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(71) Applicant: **XEROX CORPORATION**
Xerox Square
Rochester New York 14644(US)

(72) Inventor: **Appel, James J.**
87 Bradford Road,
Rochester, New York 14618(US)
Inventor: **Rossman, Kenneth R.**
3071 Canandaigua Road
Macedon, New York 14502(US)
Inventor: **Paoli, Thomas L.**
420 Cypress Drive
Los Altos, California 94022(US)

(74) Representative: **Weatherald, Keith Baynes et al**
Rank Xerox Patent Department
Albion House,
55 New Oxford Street
London WC1A 1BS (GB)

(54) Diode Lasers.

(57) A diode laser structure (10) is thermally stabilized by passing current through heater strips (28) along the sides of the diode laser cavity (26). The diode laser structure comprises a first confinement layer (14) and a substrate (12) of one conductivity type, an active layer (16), a second confinement layer (18) and a contact layer (20) of an opposing conductivity type. Disordered regions (24) extend from the contact layer through to the first confinement layer defining diode laser cavities. Resistive regions (28, 32) are formed within the disordered regions. Individual contacts on the contact layer aligned with each diode laser cavity inject current through the diode laser cavity to the contact on the substrate, causing emission of coherent radiation through an edge face of the diode laser structure. Individual contacts on the contact layer aligned with resistive regions inject current through the resistive region to the contact on the substrate, causing generation of heat. The resistive region within the disordered region forms a heater strip, and adjacent heater strips maintain the temperature within the diode laser cavity between the adjacent disordered regions of the heater strips.

The resistive region (28) can be replaced with a diffused region (50) to provide a forward biased p-n junction to form the heater strip. The contacts (84, 86) for the laser cavity and the heater strips can be interdigitated.

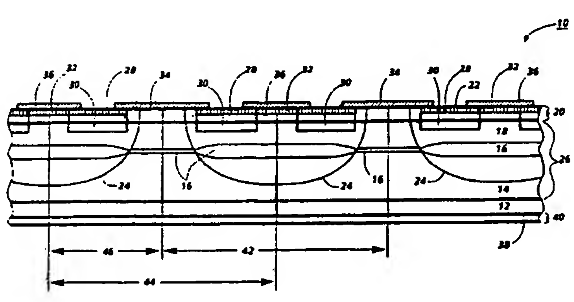

Fig. 1

This invention relates to a diode laser, and, more particularly, to a diode laser structure that has been thermally stabilised by passing currents through heater strips along the sides of the diode laser cavity.

Typical diode laser pixel times for high speed printers are in the order of 10 to 100 nanoseconds. When the laser is turned on, adiabatic heating of the diode laser cavity occurs because of the inefficiency of the conversion of electrical energy into emitted light. The heat dissipates over time periods on the order of 10 to 100 microseconds. This difference in time constants will cause the temperature of the typical diode laser cavity to vary with the pattern of the data being written. This effect gives rise to pattern dependent instability. For example, if the laser has been off for a period of several microseconds, and it is turned on for a single pixel time, the laser cavity will be at some temperature T, when it emits the light for that single pixel. If, however, the laser has been on continuously, or quasi-continuously, for a period of several hundred microseconds, is turned off for just a few pixels, and is then turned back on again, the laser cavity will be at a higher temperature, T + dT. dT can be on the order of 1 to 10 degrees Centigrade, depending on the efficiency and structure of the laser.

This change in the temperature of the laser cavity can change both the power emitted and the wavelength of the emission. These changes are detrimental to some applications of diode lasers. In particular, the instability in the wavelength of the emission may cause a focus shift and degradation of the image quality.

A technology known as distributed feedback lasers is currently being pursued to stabilise the wavelength of the emission, by using Bragg scattering to define the laser cavity, instead of mirrors. This technology, which is capable of reducing the wavelength shift, but not the change in power emitted, has resulted in relatively expensive diode lasers.

Typical known diode laser structures use a heat sink to remove heat from the diode laser structure during light emission. The heat sink temperature is maintained at a constant level by using a Peltier or thermo-electric cooler. Because of the thermal resistance between the diode laser cavity and the heat sink, this technique is not capable of maintaining the diode laser cavity at a constant transient temperature. The heat sink helps maintain an average temperature within the diode laser cavity. The laser pixel times for high speed printers occur too fast and over too short periods of time for the heat sink or Peltier or thermo-electric cooler to respond to, thus resulting in temperature fluctuations from pulse to pulse within the laser cavity.

It is an object of this invention to provide means for stabilising the temperature of a diode laser cavity, and thus to stabilize the power emitted and the wavelength of the light emission from that diode laser cavity.

In accordance with the present invention, a thermally stabilised diode laser structure comprises a first confinement layer and a substrate of one conductivity type, an active layer, a second confinement layer and a contact layer of an opposing conductivity type. Disordered regions extend from the contact layer through to the first confinement layer defining diode laser cavities. Resistive regions are formed within the disordered regions. Individual contacts on the contact layer aligned with each diode laser cavity inject current through the diode laser cavity to the contact on the substrate causing emission of coherent light through the edge of the diode laser structure. Individual contacts on the contact layer aligned with resistive region inject current through the resistive region to the contact on the substrate causing generation of heat. The resistive region within the disordered region forms a heater strip and adjacent heater strips maintain the temperature within the diode laser cavity located between the adjacent disordered regions.

The resistive region can be replaced with a diffused region of conductivity opposite to the disordered region to provide a forward biased p-n junction to form the heater strip. The contacts for the laser cavity and the heater strips can be interdigitated.

The present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic side view of a thermally-stabilized diode laser structure formed according to the present invention;

Figure 2 is a schematic illustration of the top view of the diode laser structure of Figure 1;

Figure 3 is a schematic side view of an alternative embodiment of diode laser structure of present invention;

Figure 4 is a schematic top view of another alternative embodiment of the present invention;

Figure 4A is a schematic side view through line A-A of Figure 4 and;

Figure 4B is a side view through line B-B of the diode laser structure of Figure 4.

Reference is now made to Figure 1, wherein there is illustrated a thermally stabilised diode laser structure 10 of this invention.

The diode laser structure 10 comprises a substrate 12 of n-GaAs upon which is epitaxially deposited a first confinement layer 14 of n-$Al_xGa_{1-x}As$; an active layer 16 of nondoped GaAs for providing light wave generation and propagation

under lasing conditions, a second confinement layer 18 of p-$Al_yGa_{1-y}As$ where x = or ≠ y, and a contact layer 20 of p-GaAs.

The active layer 16 may, in the alternative, be nondoped, p-type doped or n-type doped; GaAs, $Al_zGa_{1-z}As$ or $(Al_zGa_{1-z})_{0.5}In_{0.5}P$; or a relatively thin conventional double heterostructure (DH) active layer; or a single quantum well, such as GaAs or $Al_zGa_{1-z}As$ where z is very small and z<x and y; or a multiple quantum well superlattice, such as alternating layers of GaAs and $Al_zGa_{1-z}As$ where z<x and y or alternating layers of $Al_wGa_{1-w}As$ and $Al_BGa_{1-B}As$ where w<B<x or y (w for well and B for barrier). Also, in the alternative, any of the aforementioned active layers can be deposited between two semiconductor confinement layers of $Al_mGa_{1-m}As$ and $Al_nGa_{1-n}As$, where m = or ≠ n, but with the bandgaps intermediate between the bandgaps of the active layer and the first and second confinement layers, in a separate confinement structure.

As is known, the epitaxial growth of thermally stabilized diode laser structure 10 may be carried out by molecular beam epitaxy (MBE) or metalloorganic chemical vapour deposition (MOCVD). The substrate 12 may be about 100μm thick. The confinement layers 14 and 18 may have a thickness in the range of 0.1 to 1μm. The active layer 16 may be a thin conventional layer having a thickness of 50 nanometers to 2μm or may be comprised of a superlattice structure of quantum wells which may be 3 to 50nm thick. The contact layer 20 is typically 0.1 to 0.2μm thick.

There are alternative conventional techniques and diffusion/implant species for carrying out the desired disordering or the elemental implant/annealing technique. Discussion hereafter will be confined to impurity-induced disordering. However, it should be noted that other techniques and elemental diffusions or implants are equally applicable.

Upon completion of the epitaxial growth, a Si_3N_4 mask is formed on the top surface 22 of the contact layer 20 of the semiconductor diode laser structure 10, with openings exposing regions of the semiconductor structure to impurity-induced disordering. The mask protects the unexposed regions under which the laser cavities will be formed.

The laser cavities are established by first selectively diffusing a high concentration n-impurity dopant, such as silicon, into the regions of the semiconductor structure exposed through the mask. Other possible n-impurity dopant elements would include Ge and Sn.

A silicon layer is deposited in the opening in the Si_3N_4 mask and then capped with an additional layer of Si_3N_4. The diffusion of silicon is accomplished at a temperature of approximately 800°C and is maintained for a sufficiently long period, e.g. seven to eight hours, to enable the silicon to penetrate the contact layer 20, the second confinement layer 18 and the active layer 16, and partially penetrate the first confinement layer 14.

The diffusion of silicon through and into the active layer 16, the contact layer 20 and the confinement layers 14 and 18 causes an intermixing of Ga and Al in the active layer 16, the contact layer 20 and the confinement layers 14 and 18, thereby forming a n-impurity induced disordered region 24.

Between the disordered regions 24 in the structure 10 are the laser cavities 26 consisting of the nondisordered sections of the second confinement layer 18, the active layer 16 and the first confinement layer 14. The disordered regions, optically and electrically, isolate and separate the laser cavities. The laser cavities are formed by the confinement layers in the vertical direction and the disordered regions in the horizontal direction. The laser cavities extend longitudinally down the length of the semiconductor diode laser structure 10, as best shown in Figure 2.

Upon completion of the impurity-induced disordering steps, shallow resistive regions 28 are formed in the disordered regions 24 by implantation of He^+ or O^+ ions through the top surface 22. The resistive region is made by converting a portion of the top layer or layers of the semiconductor structure from conducting material to highly resistive material. This conversion can be accomplished by implanting He^+ or O^+ ions through the surface to form electronic states at energies in the bandgap of the semiconductor layers. These defect states remove electrons or holes from the doped layer thereby making it resistive.

The resistive region implantation can be made through the same mask openings as used for the silicon diffusion after the silicon diffusion has been performed and the openings have been reopened. It is also possible, but less desirable, to form the resistive region by depositing a resistive material on the surface of the contact layer. The resistive regions 28 extend longitudinally down the length of the semiconductor diode laser structure 10, parallel to the laser cavities 26, as best seen in Figure 2.

Electrically isolating strips 30 are formed in the disordered regions 24 by proton (He^+) or O^+ ion implantation through the top surface 22 to isolate portions of the resistive regions 28 as heater strips 32. The strips 30 are formed by implanting the He^+ or O^+ ions deep into the disordered regions 24 through the resistive region 28, and adjacent to both sides of the laser cavities 26 by masking a central portion of the resistive region against the deep implant. After this implant, the strips 30 provide electrical isolation between the laser and heater contacts which will be formed on the top surface

22 of the contact layer 20.

The technique for forming the resistive region is the same as that used conventionally to form the electrically isolating region in a diode laser by proton (He^+) bombardment. The difference is that the depth and dosage of the resistive region implant are controlled to produce a specific resistivity which is less than the resistivity of an implant done for electrical isolation. Typically the resistive region implant will have a few kilo-ohms of resistance while the isolation implant will have many megohms of resistance or more. Thus, the resistive region implant will be shallower and/or have a lower dosage of ions at a lower energy than the isolating region implant.

Standard masking means or other techniques are employed to form metal contacts of Cr-Au or Ti-Pt-Au on the top surface 22 of the contact layer 20. These metal contacts are used as laser contacts or heater contacts.

Laser contacts 34 are aligned with each laser cavity 26. The laser contacts extend on the top surface 22 across the nondisordered section of the contact layer 20 and across the adjacent disordered regions 24 on both sides of the nondisordered section and partially extend across the adjacent electrically isolating region 30 on both sides. Each laser contact separately, independently, and individually contacts a laser cavity.

Heater contacts 36 are aligned with each heater strip 32. The heater contacts extend on the top surface 22 across the heater strip 32 and partially extend across the adjacent electrically isolating region 30 on both sides. Each heater contact separately, independently, and individually contacts a heater strip.

The electrically isolating regions 30 have laser contacts 34 and heater contacts 36 partially extending along their top surface 22 but the laser contacts and heater contacts are electrically and physically isolated from each other.

The laser and heater contacts are typically rectangular in shape for ease in forming high density arrays and extend longitudinally down the length of the semiconductor diode laser structure 10, parallel to the laser cavities 26, parallel to the heater strips 32 and parallel to each other. Each contact, either laser or heater, is shaped by shaping the hole in a metallization mask. Both contacts can be formed simultaneously in one evaporation.

The nondisordered contact layer 20 beneath each laser contact 34 provides low electrical resistance to the aligned laser cavity 26. The heater contact 36 is directly attached to the heater strip 32 to allow current to be directly passed through the heater.

The bottom surface 38 of the substrate 12 is also metallized with Au/Ge to form a substrate contact 40. The substrate contact is for both heater and laser contacts and can be referenced to ground.

Current is injected between the laser contact 34 and the substrate contact 40 in the laser cavity 26 to forward-bias the p-n junction of the second confinement layer layer 18 and the first confinement layer 14 to cause the active layer 16 to emit a coherent laser beam. The nondisordered second confinement layer of p-$Al_yGa_{1-y}As$ is the p-confinement layer and the nondisordered first confinement layer of n-$Al_xGa_{1-x}As$ is the n-confinement layer of the p-n junction.

The current is injected through the laser contact 34, the nondisordered section of the contact layer 20, the nondisordered section of the second confinement layer 18, the nondisordered section of the active layer 16 of the individual laser diode, and then spreads in the nondisordered section of the first confinement layer 14 into the substrate 12 and out the substrate contact 40.

The substrate or ground contact is common to all the laser diodes. However, each laser cavity contains a p-n junction that is separately biased through its laser contact from all the others. Since each laser contact is positively biased with respect to ground, current flows only from each laser contact to ground. The electrically isolating regions and the disordered regions prevent any single laser contact from causing adjacent laser cavities to emit light or adjacent heater strips to generate heat. Flow between different laser contacts does not occur because any small potential difference between the addressed laser contact and a neighbouring laser contact corresponds to a reverse voltage on the neighbouring laser contact.

The light is emitted through the edge of the semiconductor diode laser structure 10 and can be either continuous wave or pulse.

Typically, the laser diode semiconductor structure 10 has an operating current of about 12 milliamperes with an output power of about 5 milliwatts per individual laser cavity 26.

Current is injected between the heater contact 36 and the substrate contact 40 to cause the heater strip 32 to generate heat. The heat generated will equal the voltage times the current or, alternatively, the heat generated will equal the current squared times the resistance of the heater strip.

The current is injected through the heater contact 36, the heater strip 32, the n-disordered region 24, and then spreads in the first confinement layer 14 into the substrate 12 and out the substrate contact 40. The substrate or ground contact is common to all the heater strips.

Since each heater contact is positively biased with respect to ground, current flows only from each heater contact to ground. The electrically

isolating regions and the disordered regions prevent any single heater contact from causing adjacent heater strips to generate heat or adjacent laser cavities to emit light.

In Figure 1, adjacent laser cavities 26 are spaced symmetrically apart with a spacing 42 of 10m. Adjacent heater strips 32 are spaced symmetrically apart with a spacing 44 of 10m. Adjacent laser cavity and heater strips are spaced symmetrically apart with a spacing 46 of 5m.

The symmetrical spacing of the adjacent heater strips 32 on both sides of the laser cavity 26 provides heating on both sides of each laser cavity. The resistive region 28 of the heater strip 32 have some finite electrical resistance. Heat will thus be generated when a current is run through the heater strip.

Thus, when current is injected through the heater strips 32, heat is generated and spreads out through the n-disordered regions 24. Since the heater contacts 36 will only be addressed in adjacent pairs, adjacent heater strips 32 will heat the laser cavity 26, which will emit the coherent radiation beam.

This technique can be used on lasers which are widely spaced apart or more tightly spaced one µm width stripe lasers with one µm width disordered regions yielding spacings of less than five µm.

As shown in Figure 2, two adjacent heater strips 32 have been fabricated along the sides of the laser cavity 26 of the thermally stabilized diode laser structure 10. As with the resistive regions and the n-disordered regions, the heater strips 32 extend longitudinally down the length of the semiconductor diode laser structure 10, parallel to the laser cavities 26.

When the current is run through the laser cavity to emit light (the laser diode is on), the current in the adjacent heater strips is reduced to zero. When the current to the laser cavity is reduced to zero (the laser diode is off), a current is run through the adjacent heater strips. The amount of current run through the adjacent heater strips, when no current is run through the laser cavity, is set to be precisely the amount needed to generate sufficient heat to maintain the temperature within the laser cavity at the same value as it was during emission of light. The temperature will remain constant within the laser cavity, regardless of how long or short a time the diode laser is on or off. Thus, the laser cavity is held at constant temperature, and the power emitted and wavelength of the emission from the laser cavity remain constant independent of the data.

To maintain the temperature of the active region during a pixel time when the current to the laser cavity is reduced to zero (the laser diode is off), the adjacent heater strips need supply only enough energy to replace the heat lost from the laser cavity. The temperature of the laser cavity will drop on the order of 1 degree Celsius for a pixel time of 100 ns. To increase the temperature of the laser cavity by 1°C, the two half cylinders of semiconductor material adjacent to the laser cavity must be heated.

The half cylinder used in the calculation is centred on one heater strip. This strip heats half of the two adjacent laser cavities, so for multiple laser structures we get the benefit of heat flow in both directions. For single laser structures or for the end laser, half the heat from each cylinder is wasted. The calculation is for each half cylinder.

For the dimensions of Figures 1 and 2 and a diode laser structure length of 250µm, the volume of the material to be heated by each heater strips is 9.8 x 10^{-9} cm^3. (The spacing of the lasers is taken to be 10µm. 5µm is then the radius of the cylinder centred on the heater strip and extended to the centre of adjacent laser cavities. The volume of the half cylinder is π xR^2 x 250 µm/2.)

For GaAs/AlGaAs with a specific heat of 0.07636 cal/gm-deg and a density of 3.6 gm/cm^3, a one °C temperature rise in 100 ns requires 113 mW. This input power can be supplied by 10 mA of current to a 1.13 kilo ohm resistor in the heater strip, or by 100 mA of current to an 11.3 ohm resistor in the heater strip. Both values are reasonable levels to obtain from a heater strip.

In Figure 3, the diode laser structure 48 is identical to the diode laser structure 10 of Figure 1, except that the resistive region 28 of Figure 1 has been replaced with a diffused region 50 in Figure 3 to form a p-n junction with the disordered region 52. Thus, the laser diode structure 48 comprises a substrate 54 of n-GaAs upon which is epitaxially deposited a first confinement layer 56 of n-$Al_xGa_{1-x}As$; an active layer 58 of nondoped GaAs for providing light wave generation and propagation under lasing conditions; a second confinement layer 60 of p-$Al_yGa_{1-y}As$ where x = or x ≠ y, and a contact layer 62 of p-GaAs.

N-impurity induced disordered regions 52 are formed in the thermally stabilized diode laser structure 48, extending through portions of the contact layer 62, the second confinement layer 60, the active layer 58 and partially extending through the first confinement layer 56.

Upon completion of the n-impurity induced disordering step, a second Si_3N_4 mask is formed on the top surface 64 of the contact layer 62 with openings exposing regions of the laser structure to diffusion of impurity atoms into the semiconductor layers. This second mask exposes a narrower, centred region of the n-impurity induced disordered regions 52, symmetrically spaced from the non-

disordered regions of the contact layer 62.

A high concentration p-impurity dopant, such as zinc, is selectively diffused into the regions of the laser structure exposed by the second mask. The diffusion of zinc is accomplished at a relatively low temperature of approximately 650° C in an evacuated heater, such as a semi-sealed graphite boat, containing appropriate diffusion and arsenic sources and is maintained for a sufficiently long period, e.g. approximately one hour, to penetrate partially the n-impurity induced disordered region 52 to form the p-diffused region 50 for a one µm deep diffusion. The p-diffused regions 50 are symmetrically centered and entirely within the n-disordered regions 52.

Other p-impurity dopants, such as Be and Mg, do not diffuse as fast as zinc through various layers. This may be an advantage allowing for better control of the depth to which the p-impurity dopant will diffuse. The diffusion step can occur before the disordering step is complete in order to avoid additional disordering during p diffusion. The diffusion step is only type conversion of the disordered region from n to p.

Electrical isolating regions 66 are formed in the n-disordered regions 52 through the top surface 64, adjacent to the p-disordered regions 50.

Between the n-disordered regions 52 in the thermally stabilized diode laser structure 48 are the laser cavities 68 consisting of the nondisordered sections of the second confinement layer 60, the active layer 58 and the first confinement layer 56.

Laser contacts 70 are formed on the top surface 64, aligned with each diode laser cavity 68. Heater contacts 72 are formed on the top surface of the p-diffused region 50, aligned with each p-diffused region. The electrically isolating regions 66 electrically and physically isolate the adjacent laser and heater contacts. A substrate contact 74 is formed on the bottom surface 76 of the substrate 54.

Current is injected between the laser contact 70 and the substrate contact 74 in the laser cavity 68 to forward-bias the p-n junction of the second confinement layer layer 60 and the first confinement layer 56 to cause the active layer 58 to emit a coherent laser beam. The nondisordered second confinement layer of p-$Al_yGa_{1-y}As$ is the p-confinement layer and the nondisordered first confinement layer of n-$Al_xGa_{1-x}As$ is the n-confinement layer of the p-n junction.

The current is injected through the laser contact 70, the nondisordered section of the contact layer 62, the nondisordered section of the second confinement layer 60, the nondisordered section of the active layer 58 of the individual diode laser, and then spreads in the nondisordered section of the first confinement layer 56 into the substrate 54 and out the substrate contact 74. The substrate or ground contact is common to all the laser cavities.

Current is injected between the heater contact 72 and the substrate contact 74 to forward-bias the p-n junction of the second disordered region 50 and the first disordered region 52 to generate heat. The p-n junction between the p-diffused region 50 and the n-disordered region 52 constitute a heater strip 78.

The current is injected through the heater contact 72, the p-diffused region 50, the n-disordered region 52, and then spreads in the first confinement layer 56 into the substrate 54 and out the substrate contact 74. The substrate or ground contact is common to all the heater strips.

As with the diode laser structure 10 of Figures 1 and 2, the adjacent laser cavities 68 are symmetrically spaced apart, the adjacent heater strips 78 are symmetrically spaced apart, and adjacent laser cavity and pair of heater strips are symmetrically spaced apart in the diode laser structure 48 of Figure 3.

The symmetrical spacing of the adjacent heater strips 78 on both sides of the laser cavity 68 provides heating on both sides of each laser cavity. Similar to Figure 2, the heater strips 78 extend longitudinally down the length of the semiconductor diode laser structure 48, parallel to the laser cavities 68. When current is injected through the p-n junction of the heater strips, heat is generated and spreads through the n-disordered regions 52. Since the heater contacts 72 will only be addressed in adjacent pairs, adjacent heater strips 78 will heat the nondisordered active layer 58, between the heater strips, which will emit the coherent light beam.

When the current is run through the laser cavity to emit light (the diode laser is on), the current in the adjacent heater strips is reduced to zero. When the current to the laser cavity is reduced to zero (the diode laser is off), a current is run through the adjacent heater strips. The amount of current run through the adjacent heater strips, when no current is run through the laser cavity, is set to be precisely the amount needed to generate sufficient heat to maintain constant temperature within the laser cavity. Thus, the laser cavity is held at constant temperature, and the power emitted and wavelength of the emission remain constant independent of the data.

To maintain the temperature of the active region during a pixel time when the current to the laser cavity current is reduced to zero (the diode laser is off), the adjacent heater strips need supply only enough energy to replace the heat lost from the laser cavity. The temperature will drop on the order of 1°C for a pixel time of 100 ns. To increase the temperature of the semiconductor ma-

terial by 1 °C, the two half cylinders of semiconductor material adjacent to the laser cavity must be heated. The heat generated by each p-n junction is given by its current times (the voltage on junction plus its internal series resistance). For the same conditions as in the thermally stabilized diode laser structure 10 in Figures 1 and 2, the p-n junction of the thermally stabilized diode laser structure 48 of Figure 3 with voltage of 1.8 V in series with a 10 ohm internal resistance will compensate for a 1 °C temperature fluctuation with 49 mA of current.

For the GaAs/AlGaAs semiconductor structure of this thermally stabilized diode lasers, the resulting p-n junction is formed in AlGaAs with Al composition high enough to make it indirect. The indirect material is especially advantageous in this case because virtually all the current passed through this junction generates heat. Indirect means the band-to-band transitions occur only nonradiatively, i.e. no radiation is emitted spontaneously. Therefore all electrons and holes recombine by giving up their energy in the form of heat without radiating light.

To reduce the time delay between the onset of the heater strip current and warming of the active region of the laser cavity, the source of the heat should be as close to the active region as possible. This also minimizes the amount of semiconductor material that must be kept warm. Thus, the p-n junction is advantageous compared to the resistive region since the junction, where the heat is generated below the surface and therefore closer to the laser cavities.

The heater contact 80 and the laser contact 82 are interleaved with heater contact fingers 84 alternating with laser contact fingers 86 on the top surface 88 of the diode laser structure 90 of Figure 4. The interleaving of heater and laser contact fingers is also referred to as interdigitated contacts. The heater contact fingers 84 extend outwardly from the heater contact 80. The laser contact 82 surrounds the heater contact 80, with the laser contact fingers 86 extending inward from the laser contact to interleave with the heater contact fingers 84. Regions 92 electrically and physically isolate the heater contacts 80 and the laser contacts 82 from each other.

Figure 4A is a side sectional view along line A-A across the laser contact finger 86 of the thermally stabilized diode laser structure 90 of Figure 4.

The diode laser structure 90 of Figure 4A is identical to the diode laser structure 10 of Figure 1, except the resistive layer 28 and resulting heater strip 32 of Figure 1 is not implanted and formed in this section of the thermally stabilized diode laser structure 90 underneath the laser contact 84. Thus, the thermally stabilized laser diode structure 90 comprises a substrate 94 of n-GaAs; a first confinement layer 96 of n-$Al_xGa_{1-x}As$; an active layer 98 of nondoped GaAs for providing light wave generation and propagation under lasing conditions; a second confinement layer 100 of p-$Al_yGa_{1-y}As$ where x = or x ≠ y; a contact layer 102 of p-GaAs; n-impurity disordered regions 104, electrically isolating regions 92; laser contact finger 86 of the laser contact 82, substrate contact 106, and laser cavity 108, formed as stated above.

The n-impurity induced disordered regions 104 extend through portions of the contact layer 102; the second confinement layer 100; the active layer 98 and partially extend through the first confinement layer 96. Between the n-disordered regions 104 are the laser cavities 108, consisting of the nondisordered sections of the second confinement layer 100, the active layer 98 and the first confinement layer 96. The electrical isolating regions 92 are formed in the n-disordered regions 104 through the top surface, adjacent to the non-disordered contact layer 102, with the laser contact 82 extending across the non-disordered contact layer 102 between the adjacent electrically isolating regions 92.

Current is injected between the laser contact 82 and the substrate contact 106 in the laser cavity 108 to forward-bias the p-n junction of the second confinement layer layer 100 and the first confinement layer 96 to cause the active layer 98 to emit a coherent laser beam. The current is injected through the laser contact 82, the nondisordered section of the contact layer 102, the nondisordered section of the second confinement layer 100, the nondisordered section of the active layer 98 of the individual laser diode, and then spreads in the nondisordered section of the first confinement layer 96 into the substrate 94 and out the substrate contact 106. The substrate or ground contact is common to all the laser cavities.

Figure 4B is a side sectional view along line B-B across the heater contact finger 84 of the diode laser structure 90 of Figure 4. The diode laser structure 90 of Figure 4B is identical to the diode laser structure 10 of Figure 1, except the n-impurity induced disorded regions 104 are formed adjacent to the resistive layer 110 in Figure 4B, with the resulting heater strip 112 aligned with the laser cavity 108 as opposed to Figure 1 where the resistive layer 28 is implanted in the n-disordered region 24 so that the heater strips 32 are not aligned with the laser cavity.

Thus, the thermally stabilized laser diode structure 90 of Figure 4B comprises a substrate 94 of n-GaAs;a first confinement layer 96 of n-$Al_xGa_{1-x}As$; an active layer 98 of nondoped GaAs for providing light wave generation and propagation under lasing conditions; a second confinement layer 100 of p-

$Al_yGa_{1-y}As$ where $x = $ or $x \neq y$; a contact layer 102 of p-GaAs; a resistive layer 110; n-impurity disordered regions 104; a heater strip 112, electrically isolating regions 92, heater contact finger 84 of the heater contact 80, and substrate contact 106, formed as stated above.

The n-impurity induced disordered regions 104 extend through portions of the contact layer 102, the second confinement layer 100, the active layer 98 and partially extending through the first confinement layer 96. The resistive layer 110 is implanted through the nondisordered section of the contact layer 102 and partially through the nondisordered section of the second confinement layer 100 between and partially extending into the adjacent n-impurity disordered regions 104. The electrically isolating regions 92 are implanted at the ends of the resistive layer into the adjacent n-impurity disordered regions 104 forming the heater strip 112 between the adjacent electrically isolating regions 92.

Current is injected between the heater contact 80 and the substrate contact 106 to cause the heater strip 112 to generate heat. The current is injected through the heater contact 80, the heater strip 112, the nondisordered section of the second confinement layer 100, the nondisordered section of the active layer 98, and then spreads in the first confinement layer 100 into the substrate 94 and out the substrate contact 106. The substrate or ground contact is common to all the heater strips.

The laser cavity 108 is underneath and extends longitudinally perpendicular to the heater contact fingers 84 and the laser contact fingers 86 in Figure 4. The heater strips underneath the heater contact fingers are intermittent at regular intervals along the length of the laser cavity, as shown by the interdigitated pattern of the laser and heater contacts.

The heater strip 112 of Figure 4B is aligned with the nondisordered second confinement layer 100, the nondisordered active layer 98 and the nondisordered first confinement layer 96 which are the laser cavity 108 of Figure 4A. The heater strip in the diode laser structure 90 of Figure 4 is on the order of 1.5 μm from the active region rather than the 5 μm used in the diode laser structures of Figures 1 and 3.

Under the fingers of the heater contact, the high resistivity regions of the heater strips are implanted, while under the fingers of the laser contacts are the low resistance sections of the nondisordered contact layers. If the contact fingers are narrow enough, the carrier density will be uniform in the active region because of current spreading in the cladding and carrier diffusion in the active layer. The laser cavity extends longitudinally perpendicular to the heater contact fingers 84 and the laser contact fingers 86. Current through the laser contact fingers will pass through the entire laser cavity to generate radiation under lasing conditions along its entire length, even the sections of the first and second confinement layers and active layers aligned underneath the heater contact fingers. Similarly, current through the heater contact fingers will pass through the heater strips and generate heat along the entire length of the laser cavity, even the sections of the laser cavity not aligned underneath the heater contact fingers.

The heater strip current does pass through the active layer of both the heater and laser sections of the laser cavity. However, the heater strip current generates heat because of resistance in the heater strips, but does not cause lasing from the active layer of the laser cavity because the heater strip current is too low.

The heater strips 112 of Figure 4 are aligned with the laser cavities 108. Therefore, heat generation is symmetric and only one heater strip is needed, as contrasted with the adjacent pairs of heater strips in Figures 1 and 3. As discussed previously with regard to the diode laser structures of Figures 1 and 3, in the laser diode structure 90 of Figure 4, when the current is run through the laser cavity 108 to emit light (the laser diode is on), the current in the adjacent heater strip 112 is reduced to zero. When the current to the laser cavity 108 is reduced to zero (the laser diode is off), a current is run through the adjacent heater strip 112.

The laser cavity of a diode laser structure has a threshold or minimum operating temperature for light wave generation and propagation under lasing conditions which must be generated within the laser cavity. A heater strip or adjacent heater strips cannot be used to reach the threshold operating temperature. However, once past that minimum temperature, the heater strip can be used to maintain the temperature of the laser cavity of a diode laser structure at the transient times or within pulse fluctuations in temperature.

Once above the threshold operating temperatures, the laser cavity of a thermally stabilized laser structure may be cooled by the emission of light. This heat loss may be balanced by the heat produced from the adjacent heater strips. Thus, current may be injected through the heater strips, even when current is being injected through the laser cavity, to produce the minimal amount of heat from the heater strips to offset the heat loss from emission of light from the laser cavity. Cooling occurs only if laser is heated above its operating temperature at the operating power.

The thermal stabilization of the diode laser structure is not restricted to the embodiments discussed but would include such diode laser struc-

tures as rib lasers, buried crescent lasers, gain-guided laser structures and buried heterostructure lasers.

Claims

1. A thermally-stabilized diode laser structure (10) comprising:

   a first semiconductor confinement layer (14) deposited on a substrate, (12) the first confinement layer and the substrate being of the same conductivity type,

   an active semiconductor layer (16) deposited on the first confinement layer, to provide light wave generation and propagation under lasing conditions,

   a second semiconductor confinement layer (18) deposited on the active layer, the second confinement layer being opposite conductivity type to the first confinement layer and substrate,

   a semiconductor contact layer (20) deposited on the second confinement layer, the contact layer being of the same conductivity type as the second confinement layer,

   at least two disordered regions (24) extending through the second confinement layer, the active layer and at least partially through the first confinement layer, the disordered regions being opposite conductivity type to the second confinement layer,

   a resistive region (28) formed in each of the disordered regions,

   at least one diode laser cavity (26) formed between adjacent disordered regions,

   at least one contact (34) on the contact layer and aligned with each laser cavity,

   at least one contact (36) formed on each resistive region, and

   at least one contact (40) on the substrate,

   such that current injected between the at least one contact aligned with the diode laser cavity and at least one substrate contact will cause light emission from the diode laser cavity;

   such that current injected between at least one contact aligned with the resistive region and said substrate contact will cause heat generation within the resistive region, and

   such that heat generated within adjacent resistive regions is used to maintain a constant temperature within said diode laser cavity.

2. A diode laser structure as claimed in claim 1, in which each resistive region is provided by a diffused region of conductivity type opposite to the disordered region, with which it forms a p-n junction adapted to generate heat when suitably biased.

3. A diode laser structure as claimed in claim 1 or 2, in which there is a resistive region (112) formed intermittently through the contact layer (102), aligned with at least one laser cavity, the resistive region extending between adjacent disordered regions, and in which there is at least one contact aligned with each laser cavity where a resistive region has not been formed.

4. The diode laser structure as claimed in any preceding claim, wherein the substrate, the first confinement layer and the disordered regions are of n-type conductivity and wherein the second confinement layer and said contact layer are of p-type conductivity.

5. The diode laser structure of any preceding claim, wherein two electrically isolating regions (30) are formed in each disordered region, each electrically isolating region being adjacent and to one side of the resistive region, between the resistive region and an adjacent diode laser cavity.

6. The diode laser structure of any preceding claim, wherein at least one diode laser cavity comprises the nondisordered second confinement layer, the nondisordered active layer, and the nondisordered first confinement layer between adjacent disordered regions.

7. The diode laser structure of claim 3 or any claim dependent there from, wherein the or each contact aligned with a diode laser cavity, and each contact aligned with the resistive region, form an interdigitated pattern.

8. A method of thermally stabilizing a diode laser structure, comprising the steps of:

   emitting radiation under lasing conditions from a diode laser cavity of a diode laser structure, and

   generating heat within the structure from current injected through a resistive region of the structure such that heat generated from each resistive region is used to maintain a substantially constant temperature within the diode laser cavity.

9. A method as claimed in claim 8, in which the heat is generated in a p-n junction of the structure.

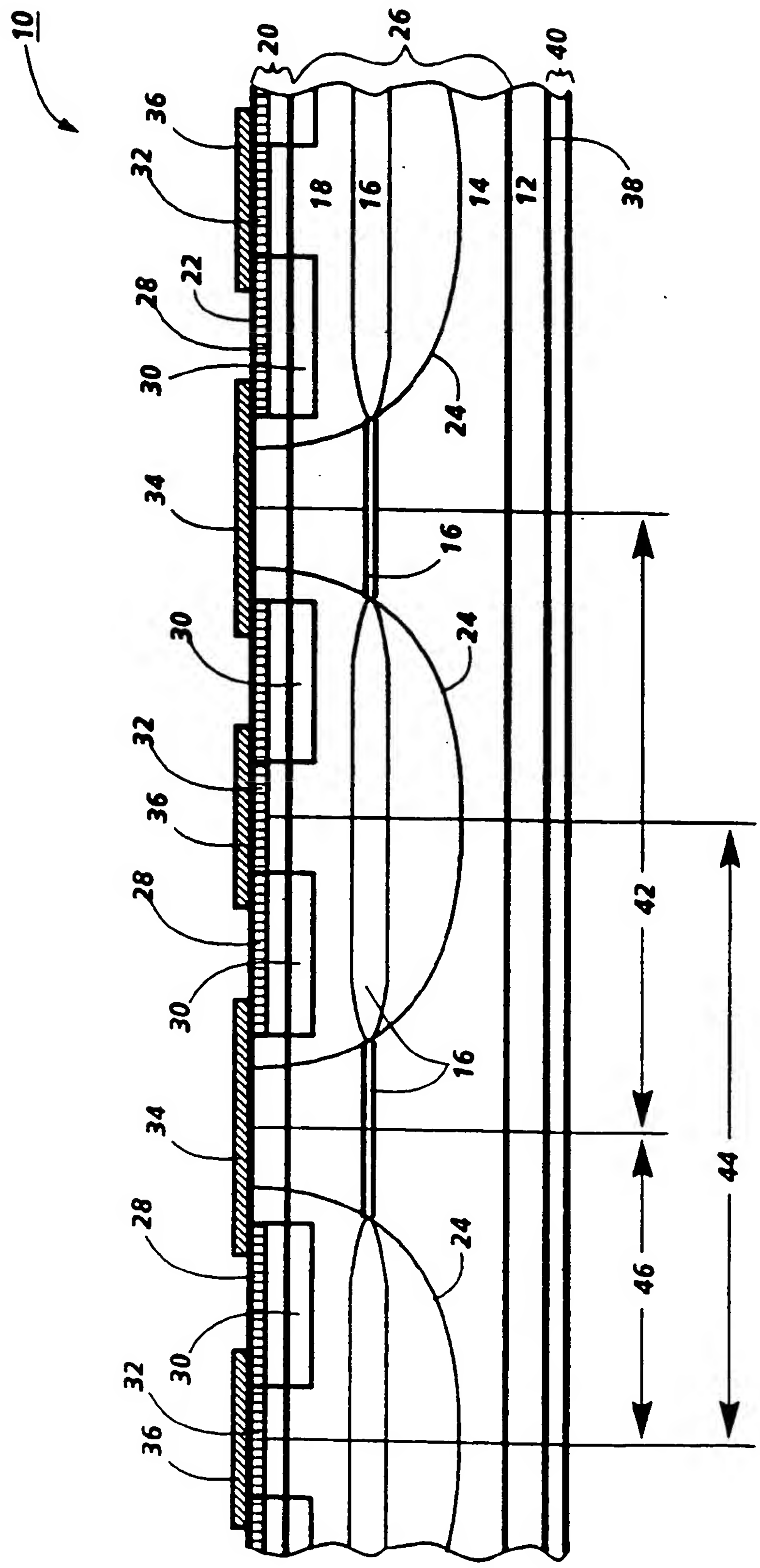

Fig. 1

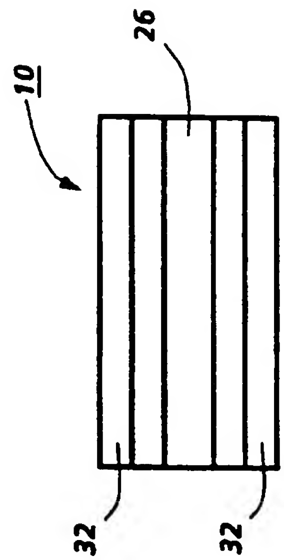

Fig. 2

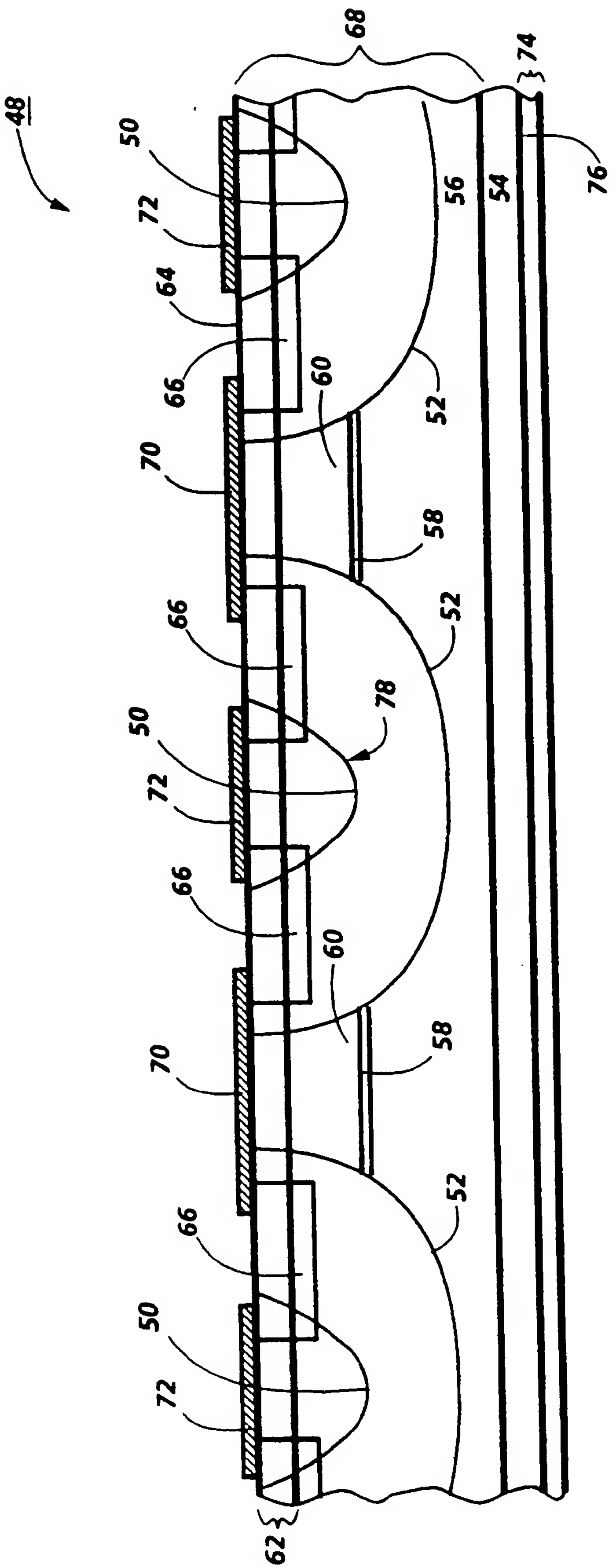

Fig. 3

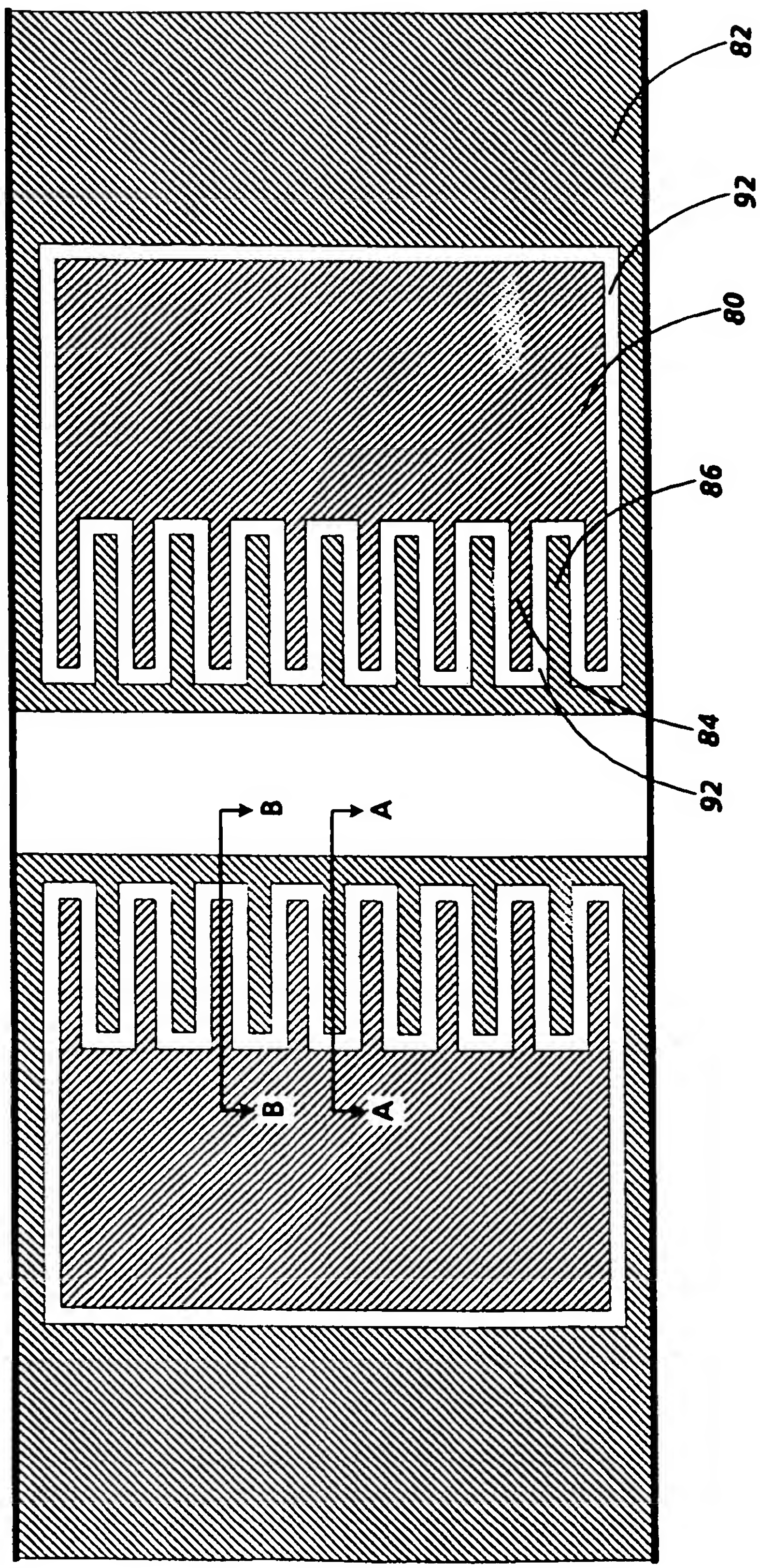

Fig. 4

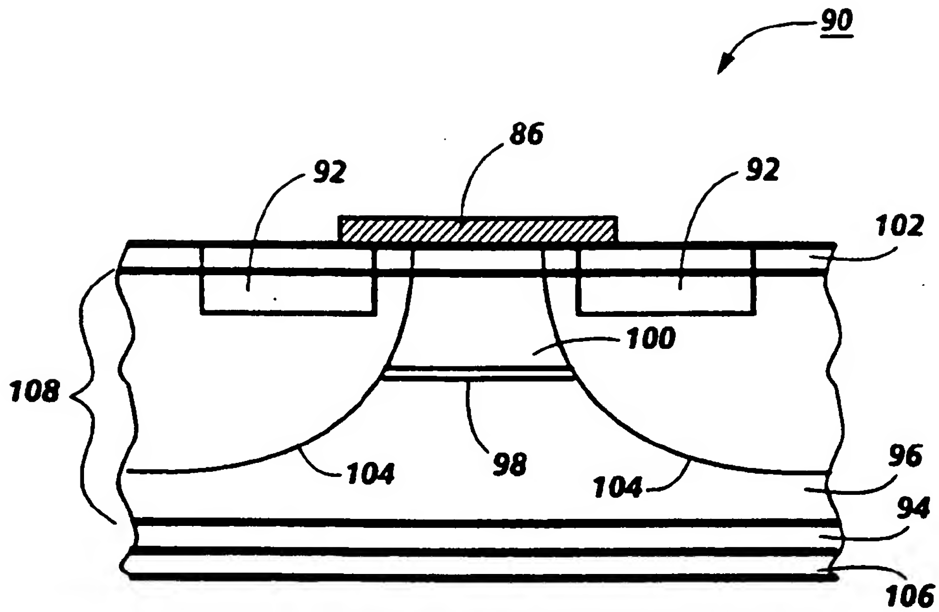
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Fig. 4A

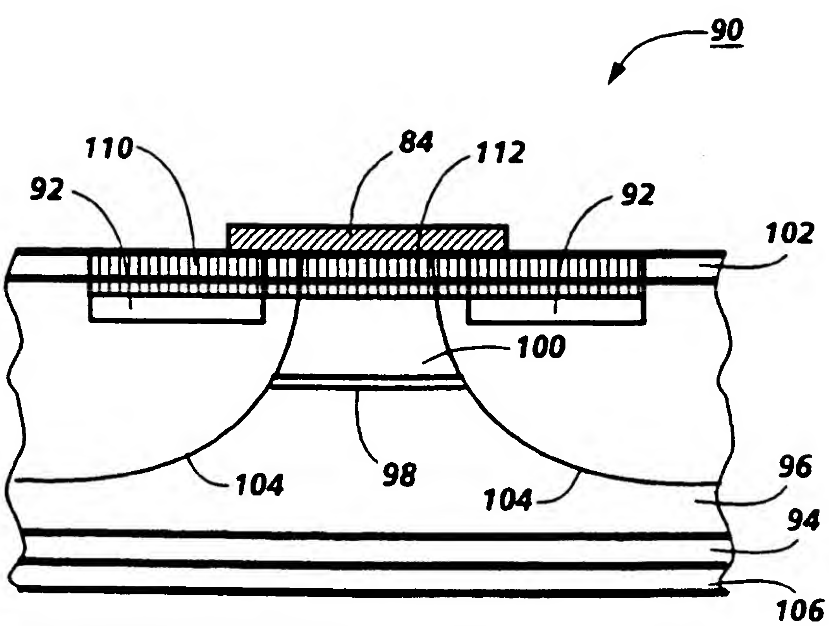
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Fig. 4B

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 30 6576

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 119 (E-499)(2566) 14 April 1987 & JP-A-61 265 885 (NEC) 25 November 1986 * abstract *	8,9 1-6	H01S3/133 H01S3/25
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 65 (E-304)(1788) 26 March 1985 & JP-A-59 204 292 (CANON) 19 November 1984 * abstract *	1,3,8	
A	PATENT ABSTRACTS OF JAPAN vol. 13, no. 407 (E-818)8 September 1989 & JP-A-01 147 885 (FUJITSU) 9 June 1989 * abstract *	1,2,8,9	
A	GB-A-2 180 985 (INTERNATIONAL STANDARD ELECTRIC) 19 September 1986 * page 1, line 45 - page 2, line 31; figures 2,4 *	1,8	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	EP-A-0 350 327 (XEROX) 10 January 1990 * column 2, line 33 - column 3, line 20; figure 1 *	1,4-6	H01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 MARCH 1993	STANG I.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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